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PLANT NEMATODES

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FOREWORD

As the damage caused by plant nematodes is becoming more widely recognized, general interest in the problem is increasing and a mounting volume of questions are being asked by producers.

This report contains background information about the status of nematode research and control at the present time. It was prepared for the use of county agents and other agricultural leaders. The first part gives information about plant nematodes in general; the second part reports individually but briefly on a few important nematodes. For readers who require detailed information about the nematode problem or about particular nematodes and methods for controlling them, a brief bibliography is appended to this report.

Warning.--Nematocides are effective in controlling some nematodes but they contain hazardous materials. To avoid danger to the user or to animals, crop damage, and the possibility of harmful residues, it is essential to read the label carefully and to follow directions explicitly in applying them.

Use nematocides only in situations and for pests recommended on the label. Do not exceed recommended dosages. Observe all safety restrictions carefully. Store all nematocides under safe conditions and in the original container to insure correct identification.

Information in this report was provided by the Crops Research Division and the Plant Pest Control Division of the Agricultural Research Service.

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PLANT NEMATODES

Plant parasitic nematodes--long unrecognized as potential causes of crop damage--are now known to cost farmers in excess of a billion dollars every year in crop losses and higher production costs.

Research in past years has now made it evident: (1) That all crop and ornamental plants are susceptible to attack by some of the many species of phytoparasitic nematodes; (2) that nematodes are capable of thriving under a wide variety of environmental conditions; (3) that they can be spread easily by movement of plants, soil, and contaminated objects; and (4) that some species are capable of surviving for long periods of time in the absence of host crops.

WHAT WE KNOW ABOUT PLANT NEMATODES IN GENERAL

Even after development of the microscope in the middle of the 17th century brought the minute plant-nematode species into easy view of scientists, early observers found it hard to believe that such insignificant-looking organisms could, by themselves, cause much damage to plants. However, in 1743, an English scientist discovered that a serious disease of wheat was caused by a nematode. In 1855, another scientist in Great Britain announced a disease of cucumbers caused by a nematode. And in 1859, a German scientist discovered the sugar beet nematode in fields affected by "beet tiredness"--a name given to describe the condition causing crop failures where flourishing sugar beet crops had once grown. Great economic importance of the European sugar beet industry which was threatened by this nematode gave impetus to the study of this species but did not immediately stimulate extensive investigation into the possible destructiveness of other plant-parasitic species.

Nematological research, both in this country and abroad, has received new impetus during the last half century and more particularly in the last 20 years. Experiments soon after World War I gave an initial stimulation to nematode research by demonstrating large differences in plant growth in soil with nematodes and soil freed of nematodes by chemicals. For many years the high cost of available fumigants restricted their use to high value crops such as pineapple. However, during the last two decades, availability of commercial nematocides which are easier and less expensive to apply than the first fumigants has contributed to producer interest in nematodes and nematode control.

Other developments that have increased public awareness of the nematode problem and stimulated nematode research include the following: (1) Alarm caused by discovery of the golden nematode in Long Island, N.Y., in 1941 and of the soybean cyst nematode in North Carolina in 1954 and by identification of the burrowing nematode in 1953 as the cause of

spreading decline of citrus in Florida; (2) systematic quarantine and control measures developed to combat these pests; and (3) passage of the Golden Nematode Act by the 80th Congress in 1948.

Considerable information about nematodes--their life histories, the damage caused by the various species, and the methods for controlling their spread and for minimizing the losses caused by them--is now available to researchers, pest control workers, and growers. Although many questions are still unanswered, knowledge accumulated during the past provides a sound basis for combating these formidable pests and for filling in gaps in our present knowledge.

Kinds and Appearance

Plant-parasitic nematodes belong to a large group of invertebrates, called round worms, which at present includes 10,000 named species. Of the identified species, some are known to be free living in soil or water and several thousand parasitic to animals. Some of the species found in the soil are predators, devouring soil micro-organisms including other nematodes. Some soil-dwelling nematodes are apparently harmless but several hundred species are harmful to plants with which they are associated.

Plant nematodes are tiny organisms. The longest of the plant-parasitic species attain a length of only about $3/16$ th of an inch and the shortest are about $1/64$ th inch. Although most of them have a characteristic slender, wormlike shape, they are too small to be identified without the aid of a microscope.

When magnified, plant-parasitic nematodes are seen to have smooth, round, unsegmented bodies without legs or other appendages. Most species are eel shaped, though the female of some important species have lemon-shaped or nearly spherical bodies.

Nematodes get their name from nema, the Greek word for thread. In fact some authors refer to them as nemas. In England and many parts of the United States plant-parasitic nematodes are called eelworms. Nematodes are also sometimes referred to as thread worms, but this term is usually reserved for nematodes that are parasitic to man or to other vertebrate animals.

Near-microscopic size of the plant nematodes makes it easy for infestations to escape detection. As a result, even conspicuous damage from nematodes is sometimes attributed to something else. Further confusing the problem, wormlike creatures found in and around plants may not be nematodes at all but oligochaetes or other small organisms. Also contributing to the difficulty of detecting the presence of nematodes is that they are typically slender and translucent. Adult females of some species are more readily visible than most other plant nematodes since they become somewhat spherical in shape at that stage.

Because of their habit of becoming permanently attached to or embedded in plant roots, endoparasitic and sedentary nematodes were observed and suspected of being plant pests long before ectoparasites

(species that live freely in the soil and feed on plants without becoming attached) were noticed and suspected of causing damage. In recent years, these free-moving nematodes, such as the dagger and sting nematodes, have been found to cause as much, if not more, plant damage than sedentary species.

Life Cycle

Though varying in particulars, the life histories of most plant-parasitic nematodes follow the same broad, general pattern. Eggs hatch into larvae which are usually similar to adults in appearance and structure. Before reaching adulthood, the larvae grow in size and develop through several stages, usually four. Each stage is terminated by a molt. After the final molt, the adult nematodes usually mate, though parthenogenetic reproduction (that is reproduction without males) is not uncommon. The life cycle of the nematode is completed when the female produces eggs for a new generation of larvae.

The minimum length of time required for completing the life cycle varies with the species of nematode, as well as with varying environmental conditions. Under optimum conditions, it is 3 or 4 weeks for some of the important plant-parasitic species. The life cycle of nematodes is made longer by periods of cold weather which slows down or inactivates them. The optimum temperature varies with the species and is higher for tropical nematodes than for species adapted to the temperate climates.

Host plants on which the nematode can feed are necessary for completion of its life cycle and absence of host plants prevents completion. If deprived of suitable food for a sufficiently long time, nematodes will starve to death. This may require only months for some species but a portion of the eggs deposited by other species may remain dormant in the soil for years.

Host Plants

Host plants are plants on which nematodes can reproduce. Every known species of plant-parasitic nematode has certain hosts on which it reproduces readily. Such plants, which are frequently severely damaged by the nematode, are said to be highly susceptible to it. Host plants on which reproduction is markedly inhibited are termed resistant. And plants on which the nematode cannot reproduce are called immune.

Some immune or highly resistant plants may be invaded by nematodes. Such plants are sometimes referred to as trap plants because they attract the parasites into an environment unfavorable for reproduction.

Some kinds of nematodes can reproduce on a large variety of host plants; others have only a few hosts.

Damage and Symptoms

The damage caused by nematodes and symptoms of nematode infection vary with the species of nematode and the part of the plant attacked. Attacks by nematodes cause plants to react in various ways--sometimes producing marked alteration in growth processes. The most common types of damage are as follows:

Root Galls

These are enlargements of the root caused by feeding of the nematode. They range in size from 1/16 of an inch to 1 inch or more. Root galls may or may not enclose the nematode that caused them.

Root Lesions

These are discolored portions of the root, composed of cells on which nematodes have fed. Very often the lesions are invaded by bacteria or fungi. During their early stages, they are the size of pin heads or smaller but later they may involve the whole root.

Root Rot

This is general decay of roots due to combined attack of nematodes, bacteria, and fungi. Frequently, nematodes make the first invasion which is followed by a secondary invasion of disease organisms.

Excessive Root Branching

This condition results from the formation of numerous short lateral roots in the vicinity of galls or other nematode injury.

Injured Root Tips

Some nematodes feed on root tips, causing them to stop growing, enlarge, or rot.

Leaf, Stem, and Flower Damage

Nematodes that invade the above-ground portions of plants cause galls, rot, twisting or distortion of leaves and stems, and abnormal development of the flower parts. Some nematodes attacking grains or grasses cause galls to form in place of seed.

General Damage

Nematode damage to roots decreases the efficiency of the root system and the ability of the plant to take up water and nourishment. The result is reduced growth and symptoms of nutrient deficiencies such as yellowing of foliage, abnormal wilting in hot or dry weather, and poor

quality of produce. Nematode attack makes plants more susceptible to other pests by weakening them and by facilitating the entrance of fungi and other secondary invaders.

The degree of nematode damage varies widely with the crop and the circumstances under which it is grown, as well as with the attacking nematodes. Some factors affecting the amount of damage follow:

- If soil is marginal or drought conditions prevail during critical growing periods, nematode damage is likely to be much greater than when soil is fertile and moisture conditions are favorable.

- Heavy infestations obviously can cause much greater damage than light infestations of the same species. However, since small populations of nematodes grow quickly into large populations if suitable food is available and other conditions are favorable, even a light infestation may build up sufficiently on a lush crop of host plants during one season to cause heavy damage to next season's crops.

- If nematodes attack young plants, damage will be greater than if the plants have had time to establish well developed root systems.

- Feeding habits and the host plant relationships of the various nematode species, of course, have a determining effect on what plants are damaged. Even when a nematode feeds on a variety of plants, it usually shows a marked preference for certain hosts and causes more damage to some species than to others. Plants that are preferred hosts and the plant species or varieties that are most damaged by a particular nematode are not always the same, however. For example, certain species of lesion nematodes prefer corn to tobacco but normally cause more damage to the latter crop when they attack it.

- In some instances, different varieties of host plants vary in their ability to survive attack by particular nematodes. When this is the case, a variety with a high degree of resistance or tolerance may be able to produce a reasonably good crop under conditions which would result in a crop failure for another variety. (See the sections on host and resistant plants, pages 3 and 9, for details regarding the ability of certain plants to survive nematode attack.)

While some of the damage to plants from nematode attack results from mechanical injury, research has demonstrated that fluids injected by the nematode into the plant sometimes are the major cause of damage.

Nematodes are now known to form a link in a number of important plant-disease complexes which at one time were attributed solely to fungal or bacterial infection. For example, the root-knot and sting nematodes increase the susceptibility of cotton to fusarium wilt to such a degree that controlling nematodes is an effective way of controlling the disease. Similarly, the tobacco stunt nematode makes tobacco more susceptible to fusarium wilt of tobacco. It has been shown that the severity of a bacterial disease of tobacco (Granville wilt) and a bacterial disease of strawberry (cauliflower disease) is due to combined attack by nematodes and bacteria.

It has also been established that a dagger nematode is the vector for the virus causing fan leaf disease of grapevines, and several other nematodes have been implicated as vectors of viruses.

Since nematode populations are seldom evenly distributed in the soil, plants showing visible damage--such as dwarfing, lack of color, and other recognizable above-ground symptoms--may be scattered unevenly through a field.

Below-ground symptoms caused by nematodes vary with types of nematodes attacking the plants. Although characteristic root galls, knots, lesions, excessive branching, and other root abnormalities are likely to betray the presence of root-attacking nematodes, this is not always the case. Some nematodes that feed on the outside of plants may retard the growth of the plant without causing recognizable symptoms in the root.

Discovery of nematodes around the roots of unthrifty plants does not, by itself, prove that the condition is caused by nematodes. All soils contain large numbers of harmless, free-living nematodes. Therefore, nematodes suspected of causing plant damage should be identified by competent authority before expensive control measures are undertaken. This precaution is the more advisable since different species of plant-pathogenic nematodes require different control measures.

How Nematodes Spread

Nematodes spread through the soil only very slowly under their own power, probably not more than a foot a month for most species, but can easily be transported by anything that moves and can carry particles of soil. The most important means of spreading nematodes in local areas are farm equipment and drainage water. Over longer distances, nematodes may be carried with farm produce, nursery plants, or top soil.

Nematode Control--Approaches, Methods and Programs

Although no easy means is available for eradicating some nematodes, effective methods of controlling or containing most destructive species have been developed through research.

Among the factors complicating the control job for farmers are the many species of nematodes, the difficulty of distinguishing between them, and the different measures required to break the life cycle of the various kinds. That most nematodes are soil borne and many species are capable of remaining dormant but viable under unfavorable conditions for long periods of time adds to the complexity of the problem. In addition, nematode populations build up rapidly when, as often happens, a small percentage survive soil treatment or rotation intended to eradicate them.

Both direct and indirect measures are used in controlling nematodes. Indirect measures aim at reducing or eradicating nematodes by preventing reproduction. Direct measures are designed to kill the nematodes. For this purpose direct control measures utilize chemicals or--in special circumstances--heating, drying, or flooding of the soil.

Rotation to Nonhost Crops

Reproduction of plant-parasitic nematodes may be prevented by denying them access to plants on which they can reproduce. The simplest way to accomplish this on a large scale is to rotate infested fields to nonhost plants.

To use crop rotation successfully in control of nematodes requires some knowledge of the kinds of nematodes present and the plants susceptible and resistant to them.

A case in point would be a tobacco field infested by a variety of nematode that attacks tobacco but is unable to feed on peanuts. If the grower knows the kind of nematode and its inability to reproduce on peanuts, he can put the pests on an extermination fare by simply planting the field to peanuts. In a single year, most of the nematode population will die out because they cannot reproduce on the immune crop. And most of the remainder will die in the second successive year of peanut planting.

In field practice this method of nematode control will permit normal production of host plants in nematode-infested fields, immediately following rotation to nonhost crops. Nematode control is undoubtedly one of the major advantages of crop rotation, if the crop sequence is selected with the nematodes in mind.

Even in areas not known to be infested by nematodes, rotation of highly susceptible crops with nonhost plants is recommended as a precautionary measure. For example, soybean growers--especially those with farms adjacent to infested areas--are advised to shift periodically to nonhost crops.

Rotation for controlling nematodes has certain limitations, however. With nematodes that attack a wide variety of plants finding a suitable non-host crop is frequently a problem. Even with the nematodes that attack only a few host plants, the trend toward specialized farming, the expense of buying equipment for handling a new crop, and the problem of acquiring the production know-how and of finding marketing channels for a crop not previously grown, all tend to discourage some farmers from rotation. Also, rotation is not practical for permanent plantings, such as orchards or vineyards. On the other hand, if a suitable alternate crop is available, rotation can sometimes be used to cut down the nematode population on infested acreage when the cost of fumigation would make it uneconomic--as for a crop having a low per-acre value.

Chemical Controls

The most widely used nematode-killing chemicals are volatile substances which fumigate the soil. These nematocides are called soil fumigants. They are applied by injection into the soil, usually at a depth of about 8 inches. With closely planted crops, the whole field is usually covered in a grid pattern (area or over-all treatment). But when the crop rows are widely separated, the fumigant may be applied only to the rows to be planted (row treatment).

The most popular soil fumigants contain dichloropropene, ethylene dibromide, or dibromochloropropane as the active ingredient. These are

inexpensive enough for use on a large scale in fields for the protection of tobacco, vegetables, and other crops of high per-acre value. At present several hundred thousand acres are treated with fumigants every year.

Fumigation is sometimes justified as a control measure to prevent a destructive nematode from spreading, even when the increased value of the crop resulting from fumigation would not be sufficient to warrant it in terms of immediate profit alone. A case in point is the successful use of fumigation to prevent the spread of the golden nematode from a small infested area of Long Island. (See the section on the golden nematode, pages 14-15, for details.)

Various other nematocides in addition to these fumigants are available. Some are effective in destroying both nematodes and weed seeds, so are widely used in seed beds. An example of this is methyl bromide. Others can be applied around the roots of living trees or shrubs without causing significant damage. These are useful in citrus groves, orchards, and ornamental plantings.

Heat Treatment

Artificial heat has limited use in nematode control because of the high cost of fuel for heating large masses of soil. It has been used mostly in greenhouses where the combined advantages of nematode control, soil-insect control, and disease control make the use of artificial heat to raise soil temperatures economically feasible.

Hot water treatments are used to a limited extent for killing nematodes infecting planting stock. Bulbs grown in nematode-infested areas are often routinely subjected to heat treatment before shipment to uninfested areas. Heat treatment is also used on some nursery stock, particularly in Florida, to eliminate nematode infection. This practice is limited, however, because of the difficulty of avoiding damage to the plant.

Plants vary in their ability to withstand heat. Generally speaking, growing plants are more susceptible than dormant ones. For example, growing nursery stock may be more susceptible to heat damage than dormant nursery stock or dried corms, bulbs, or tubers that are in dormant condition. Often the margin between the temperature lethal to nematodes and injurious to plants is very narrow.

In very hot and dry climates, a fair degree of nematode control can be obtained by simply plowing a field several times to expose the soil to combined heat and drying by sun and wind. Many nematodes are readily killed by drying; few can withstand prolonged exposure to temperatures above 110° F. such as may frequently be encountered at the soil surface in some areas; and none can withstand heating above 130° F. for more than a few seconds.

Flooding

Being adapted to life in soil of ordinary moisture content, populations of some species of nematodes can be killed by flooding the land for a period of several months.

Choosing A Control Method

Which method of controlling nematodes will be most effective and profitable in a particular situation depends on a number of factors, such as the kind of nematode, the crop involved, and other variables. Economic considerations are frequently a limiting factor. For example, whether or not rotation is practical in a given case depends on whether or not nonhost crops that can be grown profitably are available. Similarly, in the case of nematocides, cost of the chemical must be balanced against the value of the damaged crop to determine whether or not fumigation would be feasible. Generally speaking, farmers find it profitable to use all-over field fumigation only on crops with a cash value of \$400 or more an acre. If row fumigation is used, a lower per-acre value of around \$200 per acre may be sufficient to justify the cost.

Limited applicability of some other measures must also be taken into account in choosing a suitable method. Control by sun heat and dessication is feasible only under certain conditions, for example. And very few fields can be flooded for long periods to control nematodes. Nevertheless, it is usually possible to find a feasible method of control adapted to the particular circumstances.

If properly selected and used, any of the methods described in this section will give sufficient control to permit at least one reasonably normal crop of the host plant following the treatment. Except under extraordinary circumstances, none of the currently available control methods will entirely eliminate the nematodes. Nevertheless, growers will usually find that a suitable method, scientifically applied, will be profitable.

Use of Resistant Varieties

Growing resistant varieties of host plants instead of susceptible ones is the most convenient and least expensive way of combating nematodes when resistant varieties having desired commercial qualities are available.

Although only a few crop varieties resistant to nematodes are available at present, others are under development. Among the more important annual crops in which resistance is available are snap and lima beans, soybeans, peppers, sweetpotatoes, tobacco, and cowpeas. In the case of perennial plants, it may be possible in some cases to graft different susceptible but otherwise desirable commercial varieties onto rootstocks that are resistant to nematodes. For example, the S-37 peach rootstock, which is resistant to at least two species of root-knot nematode, is used for budding or grafting.

Sanitary Practices

Sanitary practices are important for keeping uninfested land free from destructive nematodes that are not generally distributed throughout any given area.

These practices include cleaning any machinery thoroughly before moving into an uncontaminated area, removing infested fields from production of host crops, and taking care not to carry the nematode by means of contaminated bags, containers, seed, nursery stock, or other farm produce.

Some situations may warrant fumigating an infested area to reduce the nematode population quickly, then rotating to a nonhost crop, or even taking it out of cultivation altogether.

Organized Control Programs

As there is a limit to what an individual farmer can do to prevent the spread of nematodes onto his land, organized control programs have been developed to contain a few nematodes of serious damage potential but limited distribution. At present, organized programs for control of the soybean cyst nematode, the golden nematode, and the burrowing nematode are in effect, with the Federal government and the affected States cooperating in combating the pests. Control measures include conducting surveys to locate infestations, quarantining of areas determined to be infested, and the placing of sanitary restrictions on general crops, nursery stock, and other commodities, soil, and machinery moving from regulated areas.

To keep new infestations from entering this country from abroad, Federal plant quarantine inspectors keep watch at ports of entry to intercept shipments containing nematodes of destructive species that are unknown or not widely distributed in this country. (See the sections on the individual nematodes for additional details regarding regulatory and control measures used to combat them.)

Outlook

Continuing research will undoubtedly refine present methods for controlling nematodes. Basic information being gathered on the life cycle of the various nematode species and their host plants will develop more efficient rotation plans for combating particular nematode species endangering valuable crops. Screening of chemicals for the control or eradication of nematodes will continue. And as more effective and less expensive nematocides are developed along with more efficient methods of applying them, the use of chemicals for nematode control will undoubtedly increase. The search for nematode-resistant plants is being pushed on a broadening front. And nematode-resistant varieties of an increasing number of annual plants and resistant root stocks for many perennials will be available in the future.

As a consequence of these studies, the problem of nematode control for some crops may be suddenly facilitated. Meanwhile, research has provided sufficient know how for reducing nematode damage in infested areas and for controlling the spread of nematode species that are potentially destructive but not widely distributed.

SOME DESTRUCTIVE PLANT NEMATODES

The remainder of this report is concerned with particular nematodes--their distribution, the crops they attack, the damage they cause, and some methods for controlling them.

Only a few important kinds among the hundreds known to attack plants will be discussed separately and these not in any great detail. Particular species were chosen for discussion either because of their economic importance or because they are typical of an important group of nematodes having similar life histories, causing characteristic damage, or posing special control problems.

In some cases where techniques for using the various control measures (such as chemical treatments or fumigation) are discussed in the first part, details are not repeated in reports on the individual nematodes.

Additional Information Sources

For more detailed information about the various nematode species, methods for controlling them, or problems peculiar to particular areas, contact the U.S. Department of Agriculture, the State agricultural colleges or agricultural experiment stations, or local representatives of farm chemical manufacturers.

Also see the bibliography appended to this report for pertinent references.

Root-Knot Nematodes

Root-knot nematode is the group name given to a number of species, genus Meloidogyne Goeldi, 1887, all having similar life histories and causing characteristic galls or knots on the roots of host plants.

Root-knot nematodes are known to occur in all parts of the United States. In the northern States, the one most commonly found outdoors is the northern root-knot nematode, Meloidogyne hapla Chitwood, 1949. In warmer regions of the country, the predominant species are the southern root-knot nematode, M. incognita (Kofoid & White, 1919) Chitwood, 1949, and the closely related cotton root-knot nematode, M. incognita acrita Chitwood, 1949. However, the peanut root-knot nematode, M. arenaria (Neal, 1889) Chitwood, 1949, the Javanese root-knot nematode, M. javanica (Treub, 1885) Chitwood, 1949, and the northern root-knot nematode are not uncommon in the South.

Larvae of root-knot nematodes enter host plants near the root tips, causing enlargements of the root tissue. Knots caused by the northern root-knot nematode are small--usually not more than an eighth of an inch in diameter--and are frequently accompanied by several short lateral rootlets developing in the root just above them. Knots caused by the other root-knot species range in size from an eighth of an inch on small roots to an inch or more on larger roots. The knots interfere with the internal structure of the roots and decrease their efficiency for transporting water and nutrients to the plant. Heavily infected root systems are reduced in size.

Inside the root, the nematodes become stationary and begin to grow in length and breadth. The females become pear-shaped and the males develop into slender worms. The adult females lay eggs from which larvae

can hatch immediately. When the plants are harvested or die at the end of the season, the larvae and eggs remain in the soil over winter and can infect the next crop.

Root-knot nematodes are able to infect and reproduce on many kinds of plants including the great majority of annuals and perennials grown for crops, as well as many weeds and ornamentals. In the warmer parts of the country, infection of crop, garden, and ornamental plants by root-knot nematodes is very common. Although infection is less common in the North, the northern root-knot nematode is sometimes a serious pest of potatoes, carrots, parsnips, soybeans, and a number of other crops.

Any given species of root-knot nematode can be controlled by a crop rotation that keeps the land in immune or very highly resistant crops for one or two years, depending on the degree of control required to produce one normal crop of a susceptible host plant. Root-knot nematodes are also easily controlled by application of any of the commercial nematocides. Under very exceptional circumstances, heating, drying, flooding, or trap crops may be useful for control of root-knot nematodes. The few root-knot resistant varieties of plants attacked by these nematodes may produce a reasonably satisfactory crop where ordinary varieties would fail.

Cyst Nematodes

Cyst nematodes, genus Heterodera Schmidt, 1871, are of considerable importance as plant pests in various parts of the United States. As with the root-knot nematodes, the larvae of cyst nematodes enter the roots of plants near the root tips, become stationary and begin to feed, growing in length and width. As they approach maturity, they break through the root surface, remaining attached to the root by the still embedded neck region. The males, which are slender worms, leave the root but the females remain attached and begin to produce eggs. Some of these may be deposited to develop immediately. As soon as hatched, larvae from the deposited eggs are able to enter new roots. With all species, some eggs are retained in the body of the female. When the female dies, her body is transformed into a cyst, with a decay-resistant outside cover. The cyst remains in the soil, enclosing and protecting the eggs which contain larvae ready to hatch. With some species, hatching in the cyst is apparently spontaneous but proceeds slowly over a period of years. With other species, hatching is accelerated by susceptible plants growing in the vicinity. Apparently an excretion from the plant roots causes the eggs to hatch.

When cyst nematodes invade susceptible plants they affect the root system, interfering with its proper functioning. As a result heavily infected plants become stunted and yellowish.

In the United States, among the best known cyst nematode species are the clover cyst nematode, the sugar beet nematode, the soybean cyst nematode, and the golden nematode of potatoes--the first because of its wide occurrence and the other three because of their damage potential.

Clover Cyst Nematode

The clover cyst nematode, Heterodera trifolii Goffart, 1932, attacks clover and various other legumes. It is apparently widely distributed in

the northeastern United States and occurs in other parts of the country also. Damage to clover has been demonstrated in experiments but is not conspicuous in fields.

Sugar Beet Nematode

The sugar beet nematode, *Heterodera schachtii* Schmidt, 1871, is found in all parts of the United States where sugar beets are grown. It is considered an important pest wherever found. The most conspicuous symptoms of attack are patches of unthrifty beets in a field. When the roots of infected plants are examined, they are found to have an abnormal number of small rootlets. Often it is possible to see small white or brownish bodies--about as wide as the shank of a common pin--clinging to the roots. These are the females.

The standard method for controlling sugar beet nematodes is crop rotation in which one or more of the many crops not attacked by the nematode are grown as an alternate crop. Depending on the severity of the infestation adequate control may require an interval of 2 to 6 years between beet crops.

The sugar beet nematode can also be controlled by nematocides. Those having dichloropropene as the most active ingredient are usually recommended. However, the use of nematocides is not economical in all cases.

Sugar beet growers whose land is not infested can protect their fields against the pest by use of sanitary practices and rotation to nonhost crops. Contaminated machinery, soil or refuse from sugar factories, and irrigation and drainage water are possible sources of infestation.

Soybean Cyst Nematode

The soybean cyst nematode, *Heterodera glycines* Ichinohe, 1952, attacks soybeans and several other species of legumes. Extensive damage has been reported only on soybeans, however. In soybean fields, above-ground damage is visible in patches of dwarfed and otherwise unthrifty plants. As the dwarfed plants are frequently a distinct yellow, the diseased condition caused by this nematode is called "yellow dwarf" in Japan. Yield reductions up to 50 percent or more may result from soybean cyst nematode infection.

Control of the soybean cyst nematode from the standpoint of the individual farmer must include crop rotation. Rotations of two or more years with almost any crop except soybeans, lespedeza, or a few other legumes is recommended.

Fumigation to increase the soybean crop is seldom practicable for individual farmers, because the per-acre return from soybeans is low. In a few special cases where an isolated infestation has been found in a previously uninfested area, pest control authorities may determine that it is good policy to use fumigation as a safeguard measure to prevent spread of the soybean cyst nematode into uninfested areas.

A plant breeding program is underway to develop new soybean strains combining resistance with other desirable qualities. Progress has been made in this direction. However, the resistance discovered is currently

linked with black-seeded beans which, because of their color, are less acceptable in the trade than yellow-seeded beans. Efforts are now being stepped up to develop a more desirable commercial variety with resistance to the nematode.

Quarantine.--Not long after the soybean cyst nematode was reported in this country in 1954, systematic surveys were started to locate infestations and all areas determined to be infested or exposed to the pest placed under Federal and State quarantine regulations. To date, surveys have confirmed the presence of the pest on about 85,000 acres in parts of 8 States--North Carolina, Tennessee, Mississippi, Arkansas, Kentucky, Missouri, Virginia, and Illinois.

The regulations provide means for safe movement from the regulated areas of soybeans and other produce, soil, farm machinery, vehicles, and other articles which might carry cysts.

Containment of the soybean cyst nematode was and continues to be important because of its great damage potential and the fact that no economically practical way of eradicating it from infested fields is available to farmers at the present time.

Golden Nematode

The golden nematode of potatoes, *Heterodera rostochiensis*, Wollenweber, 1923, had long been known as a serious pest of potatoes in England, Germany, and Holland when it was found on Long Island, New York, in 1941. This nematode attacks the roots of potato plants. When attack is heavy, severe stunting ensues with considerable reduction in yield. The golden nematode can also cause damage to tomato plants.

Quarantine.--Shortly after the golden nematode was discovered, New York State took regulatory action to slow down and prevent the spread of the golden nematode. Later the U.S. Department of Agriculture joined with New York in the effort, by aiding in enforcement of the State quarantine and organized control programs. This early regulatory action is largely responsible for holding the golden nematode in check and for preventing its spread throughout all of Long Island and the potato-producing areas of the United States.

Quarantine regulations prohibit the sale or disposal of seed potatoes from regulated areas and require that all potatoes offered for sale from these areas be packaged in paper, non-reusable containers. Regulations also apply to top soil, nursery stock, used burlap bags, and root crops. As a result of these measures the gross acreage known to be infested on Long Island, after 21 years of experience with the pest, is only 15,800 acres. About 9,300 of the infested acres have been used for housing or industrial development, leaving 6,500 infested acres available to agriculture.

Control Measures.--In 1946, about 1,500 acres of infested land on Long Island were fumigated with a mixture of dichloropropene and dichloropropane in the first large-scale attempt to control or eradicate the golden nematode by chemical means. Although this effort reduced the viable nematode population to a low level, eradication was not achieved. The survival of a small percentage of the nematodes was attributed to the fact that the nematocide vapor in the top inch or two of soil was too diluted

with air to kill the organisms at that level. To overcome this situation, twice as much fumigant was used in tests resumed in 1955 and the fumigant put in the soil in two applications, 10 days apart, with turning of the soil in between.

Success of these tests in eradicating the golden nematode provided the basis for the present treatment program inaugurated in 1960.

Search for Resistance.--Good progress in the potato breeding program for golden nematode resistance has been reported by the New York State Agricultural Experiment Station. Resistance from the Peruvian species of potato, Solanum andigenum, has been incorporated into Solanum tuberosum and the original progeny of this cross back-crossed with desirable varieties of Solanum tuberosum. According to present plans, the resistant selections will be increased at a foundation seed farm and made available to commercial seed growers. If, as presently expected, the resistant potato variety becomes available to Long Island potato growers within a few years, this will aid the present golden nematode control program.

Burrowing Nematode

The burrowing nematode, Radopholus similis (Cobb, 1893) Thorne, 1949, is a widespread pest of plants in tropical and subtropical regions of the world. This pest came into prominence in Florida in 1953 when it was reported to be the cause of "spreading decline"--a serious disease of citrus. The name "spreading decline" comes from the characteristic symptom of spreading damage to citrus groves. Intensive surveys have demonstrated the presence of this nematode on 12,000 acres of Florida citrus land.

The burrowing nematode feeds on the outer layers of the young roots of plants, destroying cells. The destroyed tissue may be invaded by bacteria and fungi, causing a general rotting of the roots. If a sufficient part of its root system is destroyed, the plant becomes sickly and off-color. Citrus trees make little or no new growth, twigs and branches die, foliage is sparse, and fruit production is low.

The burrowing nematode attacks many other plants, including numerous ornamentals.

Control Measures.--Since 1955, the Florida Department of Agriculture and the United States Department of Agriculture have cooperated in control of this pest. The Plant Pest Control Division of USDA's Agricultural Research Service has the assigned responsibility for conducting surveys and the operation of a laboratory for the processing and identification of nematodes. The State is responsible for the regulatory and control aspects of the program.

The "push and treat" method of control--based on several years of research of the Florida Citrus Experiment Station--has been adopted. Under this system diseased trees are removed and burned. The land is then fumigated by injecting a fumigant containing dichloropropene at the rate of 60 gallons per acre into the soil at a depth of 12 to 14 inches. No citrus or other host plants are permitted to grow on the treated soil for a 2-year period.

By 1961, the majority of the groves affected by spreading decline had been pushed and treated. The remaining groves, while in a state of decline, were still productive.

In 1961, the control program was modified by the initiation of a barrier or buffer-zone method of control. Under this system, one or more rows of trees on the periphery of the infested area are removed and a chemical barrier is established in the soil. The barrier or buffer zone, which ranges from 25 to 100 feet in width, is treated with ethylene dibromide at the rate of 25 gallons to the acre every six months. The treated zone is kept free of weeds and host plants by the use of an herbicide.

Florida has also adopted an aggressive program to make sure that nursery trees for starting new groves or replanting missing trees in established groves are free from the nematode. Approval of sites for all new nurseries is also required. A close surveillance is maintained over Florida's 4,600 ornamental nurseries and small-plant establishments.

Citrus Nematode

The citrus nematode, Tylenchulus semipenetrans Cobb, 1913, is found in all of the citrus-producing regions of the United States and of most of the rest of the world as well.

The female of the citrus nematode is found with its head embedded in the young roots and its kidney-shaped body outside the root. The nematode is not very conspicuous, however, since its body is regularly covered by a gelatinous egg mass to which particles of soil adhere. Heavily infected roots become darkened and appear larger in diameter than healthy roots because of the adhering soil. But no distinct knots are formed. Affected trees show symptoms of root damage. Foliage is small and off color. When trees are heavily infected, there is lack of growth and dieback, with dead twigs showing at the top of the trees. Fruit yields decline and fruit is smaller.

Control in new citrus groves starts with nematode-free planting stock since planting stock is the most likely source of existing infections. If nematode-free stock cannot be obtained, the nematodes can be killed by a hot-water treatment. This consists of immersing the roots of the infected stock in water hot enough to kill the nematodes but not hot enough to injure the plants. The margin between killing the nematodes and killing the roots is a very narrow one at best and may be influenced by the state of dormancy of the trees or other factors. In most locations, the nematode-free stock should be planted in fumigated soil.

Control methods for established citrus groves are still in the early stages of development. Under Arizona conditions, good control has been obtained by the application of 2 or 3 gallons of 1,2-dibromo-3-chloropropane (DBCP) in 5 or 6 inches of irrigation water. This reduces the nematode population by more than 99 percent and infection remains low for 2 or 3 years while growth and yields improve. Although the tree eventually returns to its former highly infected state, at present there seems to be no reason why it should not be re-treated at intervals. This method of treatment has not been successful in Florida, however. In fact, severe injury to citrus trees from DBCP has been reported there.

Sting Nematodes

Sting nematodes, Belonolaimus longicaudatus Rau, 1958, and other species, occur through the southern States on sandy soils of the Coastal Plain. They are ectoparasites--not entering the roots of plants or becoming attached to them.

Sting nematodes feed on the root tips and along the length of small tender plant roots. This causes death of cells, stunting of the roots, and various growth abnormalities. As with other nematodes, a severe infection causes the plant to show symptoms of nutrient and water deficiency. Damage to seedlings and transplants is frequently severe; attacks on germinating seeds may prevent the young plants from emerging above ground. And stunted plants may never recover completely.

Sting nematodes have been reported attacking a large variety of host plants, including trees and other perennials as well as annual crop plants. Among the plants found to be highly susceptible to these nematodes are fescue, Florida beggarweed, rye, wheat, oats, soybeans, cotton, corn, and some varieties of peanuts and cowpeas. Sting nematodes have also been reported as among the more important of the many nematodes causing damage to lawn grasses in Florida and have been found associated with damage to citrus trees and flowering dogwood. Resistant and immune plants have also been reported. For example, Kobe lespedeza, crimson clover, and Dallisgrass were found in greenhouse experiments to be relatively resistant and tobacco and watermelon plants highly resistant to sting nematodes.

Apparently the sting nematode is easily controlled by the standard nematocides, and can also be controlled by rotation.

Lesion Nematodes

More than 20 known species of the genus Pratylenchus Filipjev, 1934, are called lesion nematodes. They are found in the outer layers of young roots of plants and in other underground parts of plants such as tubers and rhizomes. Lesion nematodes kill the cells on which they feed. The damaged tissue is easily invaded by bacteria and fungi which extend the damage. The primary lesion caused by Pratylenchus species can often be seen as a very small reddish spot on a root. Such lesions may contain only a single nematode. But as the nematode population is increased by the hatching of eggs laid by the female in the root, the lesion is enlarged and frequently the whole root cortex becomes discolored.

In tobacco, the injury initiated by lesion nematodes is called brown root rot. In its early stages, this condition is characterized by a brownish lesion. And, in the later stages, by extensive rotting and sloughing of the root cortex. Similar damage is found on many other crop plants.

Lesion nematodes attack a wide variety of plants, including annuals and perennials. For example, cherry trees, alfalfa, corn, and tobacco are known to be injured by these nematodes. And although extensive data on losses are not available, lesion nematodes undoubtedly cause a very large amount of damage.

Control of lesion nematodes by nematocides such as ethylene dibromide or a mixture of dichloropropene and dichloropropane is comparatively simple, but not always economically feasible. Undoubtedly control by rotation is also possible, since lesion nematodes have resistant and immune plants as do other nematodes. Use of rotation for control is hampered at present, however, by the lack or incompleteness of lists of susceptible and immune plants for the various species.

Stem Nematodes

The stem nematode, Ditylenchus dipsaci (Kühn, 1857) Filipjev, 1936, and its relatives have long been recognized as serious pests of some ornamentals, particularly narcissus and hyacinth. The stem nematode has also been reported as infecting a considerable variety of other plants in the United States, including alfalfa, clover, garlic, and onions. A related species, the potato rot nematode, D. destructor Thorne, 1945; is occasionally a severe pest of potatoes.

Stem nematode larvae pass into a quiescent or dormant stage when subjected to drying. Their ability to remain alive for years in this stage increases the risk of spreading stem nematodes in debris from bulbs or with cured hay.

As the name implies, stem nematodes are typically found in the stems of plants or in botanically related tissues, such as bulbs and tubers. In narcissus bulbs, their presence is suggested by the characteristic "brown-ring" symptom which can be easily seen if the bulb is cut across.

Nematodes are not the only organisms which can cause such symptoms but the infection by this species can be confirmed by placing a little of the discolored tissue and some of the adjacent healthy tissue in water. If stem nematodes are present, they emerge from the tissue and can soon be seen in the bottom of the dish. The relationship of stem nematodes to onions is similar to their relationship with narcissus. In the former case, however, the injury is known as onion bloat. Leaves become curled and distorted and soft or rotten patches appear on the onion bulbs. When bulbs are heavily infected, farmers frequently find it necessary to discard them as culls. If not properly disposed of, the infected culls can be a source of infection.

When alfalfa stems are infected, they become shortened and thickened, and the leaves are small and crowded closely together. Presence of the nematodes is confirmed in the same way as with bulbs. In addition, microscopic examination of damaged portions will show that the cells have separated.

Control of the stem nematode has two aspects: (1) Infected bulbs are freed of nematodes by the hot water treatment to make them safe for planting and shipment; and (2) field infestations are controlled by nematocides or by crop rotation, combined with sanitary practices.

Bud and Leaf Nematodes

Bud and leaf nematodes belong to a large group, all members of the genus Aphelenchoides Fischer, 1894. As their name implies, bud and leaf nematodes feed on the buds and leaves of plants.

Among the best known of the bud and leaf nematode species in this country are the spring crimp nematode and the summer crimp nematode, both of which attack strawberries, the white tip nematode of rice, and the chrysanthemum foliar nematode.

The spring crimp nematode, A. fragariae (Ritzema Bos, 1891) Christie, 1932, is adapted to cooler temperatures than the summer crimp nematode. The former species is found in the United States along the Atlantic Seaboard from Cape Cod to Maryland, associated with a bud disease of strawberry plants known as "spring crimp" or "spring dwarf." The spring crimp nematode has also been reported in scattered areas of the Pacific Northwest.

The summer crimp nematode, A. besseyi Christie, 1942, of strawberries has been reported along the Atlantic Coast from Maryland to Florida and in Louisiana and California. This species attacks the young leaves of strawberry plants, deforming the leaves and killing heavily infected plants or making them worthless for fruit production. At present the only recommended control measure is to set nematode-free plants in nematode-free soil.

No morphological differences have been found between the nematodes causing summer crimp in strawberries and those causing white tip disease in rice. Infestations of the rice-attacking nematode have been found in Arkansas and Louisiana. The nematode can be controlled by seeding in water.

The chrysanthemum foliar nematode, A. ritzemabosi (Schwartz, 1911) Steiner, 1932, attacks the buds and leaves of a variety of florals such as the aster, dahlia, delphinium, phlox, and zinnia. However, it is seldom encountered on anything but chrysanthemums in the United States. During the summer it becomes a leaf parasite, causing segments of the leaf to turn yellow, then brown, and finally black. Leaf spots are frequently angular in outline, because the leaf veins retard the spread of the parasite. Good control of this nematode has been obtained by repeated spraying with parathion. In greenhouses, leaf injury caused by this nematode can be controlled by keeping the foliage dry.

Seed-Gall Nematodes

Some nematodes of the genus Anguina Scopoli, 1799, invade the developing flower parts of grasses thus causing the formation of galls in place of seed. The best known of the seed-gall nematodes are the wheat nematode, Anguina tritici (Steinbuch, 1799) Filipjev, 1936, and the bentgrass nematode, Anguina agrostis (Steinbuch, 1799) Filipjev, 1936.

Both are most commonly seen in the galls which may be mixed with wheat or bentgrass seed and which can be easily distinguished from the seed. The wheat gall is generally smaller and much darker than a normal wheat grain. The gall of the bentgrass nematode is larger than the seed and purplish in color. If these galls are cut open in water, the contents gradually emerge. Under the microscope they are seen to be a mass of tiny worms, which are the larvae of the nematodes. If galls are sown with the seed, wheat or bentgrass may become infected.

Distribution of both nematodes in the United States is limited. The wheat nematode is found occasionally in the east from Virginia and Maryland to Georgia but not in the part of the country where most of the wheat is grown. The bentgrass nematode is of interest only in the Pacific Northwest where bentgrass seed is produced. When infection of either nematode is severe, the crop may not be worth harvesting.

Control of the seed-gall nematodes starts with the planting of gall-free seed. In addition, infested land should not have been used for growing a host crop for two years immediately prior to planting wheat or bentgrass. Either nematode can be controlled by any method which breaks its life cycle. In the case of bentgrass, this can be done by application of herbicides to prevent formation of seed heads.

Stubby-Root Nematodes

Stubby-root nematodes, genus *Trichodorus* Cobb, 1913, were not recognized as plant parasites until 1951 when Christie and Perry reported attack and demonstrated injury to beets, celery, and sweet corn in the vicinity of Sanford, Florida. Since that time, stubby-root nematodes have been found to be widely distributed in the United States and many new species discovered.

Stubby-root nematodes are ectoparasites, feeding on the roots of plants from the outside, mostly at or near the root tips. This stops the growth of the root, which accounts for the name of the nematode. When enough roots are attacked to cause extensive reduction in the root system, the plant suffers from lack of water and nutritional deficiencies, with the usual stunting and poor yield.

Control by nematocides is possible. However, the ability of the few stubby-root nematodes surviving chemical treatment to multiply at a rapid rate frequently limits the value of this control method. Control by crop rotation is possible.

Dagger Nematodes

Dagger nematodes, genus *Xiphinema* Cobb, 1913, are widely distributed in the United States. They attack a large number of annual crop plants and perennials, feeding on the young roots, near the tips. This interferes with growth of the root and sometimes causes the formation of galls. Among the plants known to be damaged by these nematodes are pine trees, strawberries, and rose bushes. Damage is in proportion to the intensity of the attack, with considerable stunting occurring. Control by crop rotation is possible when plants resistant to the species involved are known.

Nematodes of this group are among the largest of the plant-parasitic nematodes. They range in length from about 1/16th to 3/16th of an inch.

Lance Nematodes

Lance nematodes, genus Hoplolaimus Daday, 1905, are widely distributed. Although they often turn up in circumstances which suggest that they are parasites of some importance, these nematodes have not been extensively studied. Lance nematodes feed on the roots of a large number of crop plants, including cotton, corn, sugarcane, red clover, St. Augustine grass, Bermudagrass, centipedegrass, and manilagrass. They usually feed from the outside of roots, but are sometimes found embedded in the root tissue. When infection is heavy, feeding is followed by disintegration and decay of the root cortex.

Spiral Nematodes

Spiral nematodes, genus Helicotylenchus Steiner, 1945, are very common in all parts of the United States and also in many tropical and subtropical countries. They are best known as parasites of boxwood and bluegrass but have also been observed on many other plants including spider lilies, African violets, and tobacco. The spiral nematode feeds with the anterior end of its body inserted into young roots. This causes lesions which are extended by bacteria and fungi. The ordinary control methods, using nematocides and rotation, are applicable.

Stunt or Stylet Nematodes

The stunt or stylet nematodes, genus Tylenchorhynchus Cobb, 1913, are best known as parasites of tobacco, corn, sugarcane, wheat, Sudan-grass, and potato. Several experiments showing plant injury caused by these nematodes have been reported as well as a large number of field observations of their association with injury. Damage is apparently similar to that caused by spiral nematodes.

SOME PLANT NEMATODE REFERENCES

This report has been limited to broad, general facts about plant nematodes as a group and to brief, summary reporting of salient information on individual species. More detailed information about nematology or nematodes and methods for controlling them is available in other publications. A few publications¹ on the large field of nematology or its particular aspects are listed below:

Controlling Nematodes in the Home Garden--by J. R. Christie and A. L. Taylor. U. S. Dept. of Agr. Farmers' Bull. No. 2048.

¹Because of the great amount of nematode research done and reported by the State Agricultural Colleges, no attempt has been made to include all pertinent State publications in this list. The State colleges and agricultural experiment stations are valuable sources of information about nematode problems in the various States, however.

The Golden Nematode of Potatoes and Tomatoes: How to Prevent Its Spread--by Joseph Spears. U.S. Dept. of Agr. Leaflet No. 361.

Nematode Control on a State-Wide Scale--by Joseph F. Spears: Agricultural Chemicals, June 1962 issue.

The Nematode Problem--by Joseph Spears: Agricultural Chemicals, January-February 1959 issue.

Nematologica--Quarterly periodical, published in Leiden, Holland. (This magazine, which is associated with the Society of European Nematologists, contains articles in several languages, including English.)

Plant Diseases: 1953 Yearbook of Agriculture. U.S. Dept of Agr. (For sale by the Superintendent of Documents, Government Printing Office, Washington 25, D.C. \$2.50)

Plant Disease Reporter--Monthly Periodical. Crops Research Division, Agricultural Research Service, U.S. Dept. of Agr.

Principles of Nematology--by Gerald Thorne. McGraw Hill, New York, N.Y., 1961.

Phytopathology--Monthly Periodical, Published in Ithaca, N. Y. (Organ of the American Phytopathological Society)

Plant Nematodes: Their Bionomics and Control--by Jesse R. Christie, Agricultural Experiment Stations, University of Florida, Gainesville, Fla., 1959.

The Soybean Cyst Nematode: A New Pest. U.S. Dept. of Agr. Program Aid No. 333 (out of print).

Soybean Cyst Nematode: Progress in Research and Control. U.S. Dept. of Agr., ARS Special Report No. 72, August 1961.

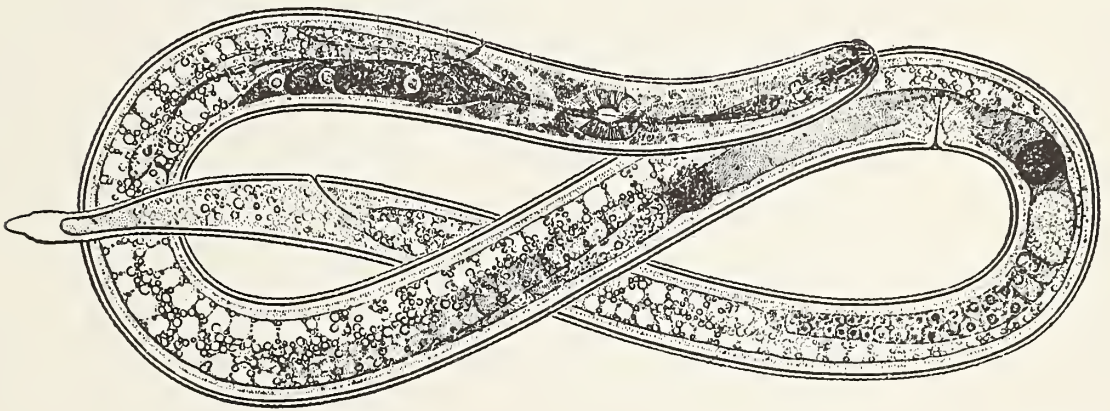
The Sugar Beet Nematode and Its Control--by A. Morgan Golden and Edsel C. Jorgenson. U.S. Dept. of Agr. Leaflet No. 486.

Symposium on Concepts and Problems of Nematology--Plant Pathology; Problems and Progress, 1908-1958 pp. 383-434. Published for the American Phytopathological Society by the University of Wisconsin Press, Madison, Wis., 1959. (The symposium includes an Introduction--by J. N. Sasser, Chairman; Historical Highlights of Nematology--by D. J. Raski; Variation in Nematodes--by Gerald Thorne and M. W. Allen; Mechanisms of Nematode Injury to Plants--by J. R. Christie and V. G. Perry; and Progress in Chemical Control of Nematodes--by A. L. Taylor.)



PN-597

This photo-micrograph shows o spiroi nematode ottocking the root of a soybean plant.



BN-17065

This is a greotly magnified drawing of o burrowing nematode, a serious pest of citrus in Florida. The eel-like shope is typical of most plant parositic nematodes.



BN-271

The round bolls ore adult females of the golden nematode, greotly magnified.



BN-12775

The grape seedling roots at left are healthy but roots at right show galling caused by root-knot nematodes.



BN-17066

This tree shows typical decline symptoms resulting from a heavy infection of burrowing nematodes.



BN-10634

Bare spots in this field mark heavy infestations of sugar beet nematodes.

